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LFG Utilization in Hong Kong
(Case study of the Shuen Wan and Urban Landfills)

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ABSTRACT

This paper provides a case study of landfill gas (LFG) utilization for direct use as process fuel, and for electrical power generation at restored landfills in the Hong Kong Special Administrative Region of China (HKSAR). The paper specifically covers the LFG utilization schemes, which are required under landfill restoration contracts at the Shuen Wan and Urban Landfills. These contracts provide for the restoration and aftercare of six landfills, and are administered by the Environmental Protection Department (EPD) of the Hong Kong Government.

The LFG utilization scheme at the Shuen Wan Landfill incorporates the direct use of LFG by compressing and dehumidifying the LFG prior to conveyance through a 1.6-kilometer (1-mile) pipeline. The pipeline provides an alternate fuel source to naphtha during process heating for gas production at the Tai Po Gas Production Plant of the Hong Kong and China Gas Limited (HKCG).

The LFG utilization scheme at the Jordan Valley Landfill (one of the Urban Landfills) beneficially uses the LFG as fuel for electrical power generation with reciprocating internal combustion engines. The LFG is compressed, cooled, and filtered prior to delivery to two engine/generator sets. This system provides power to operate the leachate pre-treatment plant, which processes leachate from all of the Urban Landfill sites.

The case study will examine the technical and non-technical considerations, including barriers, for developing, designing and implementing the LFG utilization projects in Hong Kong. Specific regulatory considerations and external governmental agency approvals are discussed, including the requirement to register as a gas-producing utility.

While the paper focuses on LFG utilization applications in Hong Kong, many of the considerations discussed are also applicable to development of LFG utilization in other regions of Asia.

INTRODUCTION

There are a total of fifteen landfills in Hong Kong. Three are currently in operation with design capacities between 35 and 61 million cubic meters(m^3) to meet Hong Kongs municipal solid waste production of approximately 9,000 tons per day[1]. The remaining landfills have been closed, and are progressively being restored under contracts with the EPD. The restored landfills discussed in this case study are the Shuen Wan and Jordan Valley Landfills.

These landfills are administered by the EPD under two public works contracts. The contracts include the design and restoration of these landfills, with maintenance and monitoring thereafter for an aftercare period of 30 years. The landfill restoration includes facilitation of potential after-use, such as recreational facilities. As part of the restoration contract requirements, LFG must be controlled(off-site migration and surface emissions) and at a minimum, utilized for on-site purposes.

Shuen Wan Landfill

Located in the eastern portion of Hong Kong, the Shuen Wan Landfill operated from 1974 to 1995, covering a site area of 50 hectares with approximately 14 million tons of waste in place. Thirty-eight gas extraction wells and a flare facility with two-enclosed flares(2500 m^3/hr capacity each), had been installed to control off-site migration prior to the award of the restoration contract. A passive trench venting system and a series of LFG monitoring probes were also installed along portions of the perimeter of the site. Further expansion of the collection system was completed in 1996 with the addition of forty-nine gas wells (eighty-seven in total) to provide comprehensive collection system coverage over the entire landfill.

The LFG compression/treatment facility was constructed in 1999. Prior to construction of the facility, the

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collected LFG was flared to mitigate the potential for off-site migration and surface emissions. The utilization scheme currently treats and compresses approximately 1200 m^3/hr of LFG which is conveyed through a 1.6-km underground pipeline to a nearby gas production plant owned by HKCG. The LFG is directly used as an alternative fuel to substitute for naphtha in process heating applications, as part of the utility gas (commonly referred to Towngas) production process.

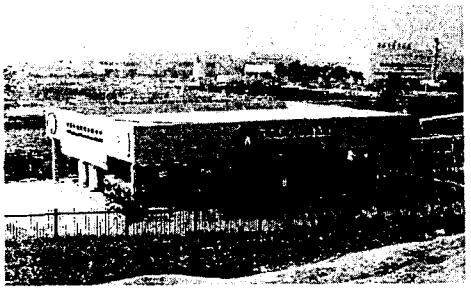

Fig. 1. Overview of Landfill Gas Compression/ Treatment Facility at the Shuen Wan Landfill

Fig. 2. Overview of Landfill Gas to Electricity Facility at the Jordan Valley Landfill

Jordan Valley Landfill

Located in Eastern Kowloon, the Jordan Valley Landfill covered an area of 11 hectares, where approximately 1.5 million tons of waste was placed. This and four other nearby landfills (Ma Yau Tong Central, Ma Yau Tong West, Sai Tso Wan and Ngau Chi Wan Landfills) were recently restored under the Urban Landfills Restoration Contract. The Jordan Valley Landfill is situated in urban surroundings, in close proximity to public housing estates (which did not exist then at the time of landfilling).

Prior to award of the restoration contract, a series of monitoring probes were installed around the perimeter of the site, however, an active gas control system was not yet in place. As part of the restoration contract, an LFG management system comprising 20 combined LFG/leachate extraction wells and a flare plant were constructed and placed into operation in 1998. A leachate pre-treatment works (LPTW) was also constructed during the same period to provide leachate treatment prior to discharge to the public sewer. An LFG-to-electricity utilization scheme was implemented in 1999 to beneficially utilize the LFG. The electrical power generated is currently used to meet the 24-hour demand for operation of the LPTW.

Non-TEchnical considerations

This section explores commercial aspects and the non-technical considerations, including barriers encountered during the implementation of the two LFG utilization schemes. Special emphasis is placed on differences between local and overseas situations.

Market Incentive

In Hong Kong, both closed and operating landfill sites are operated under contracts with the Government. Charges are imposed only on waste disposal of certain types of waste only. Contractors operate these landfills for a fee on a design/build/operate basis. This practice differs from markets where landfill owners derive their income from tipping fees for waste disposal on the landfill.

Due to gas and electrical market conditions, which are discussed in subsequent text, it is difficult to develop a utilization project for off-site sales of gas or electricity. The remoteness of most of the landfill sites makes it equally difficult to identify a potential end-user of this alternative energy source. The EPD encourages the beneficial use of the LFG in their contracts for operation or restoration of landfills. The EPD requires at a minimum, an on-site LFG utilization scheme, and where possible, sale of the LFG (or power) for use off-site.

Where off-site use is not considered feasible, use of LFG as an on-site alternative energy source is

undertaken as a requirement under the contract. In Hong Kong, no regulation has been established similar to the Public Utility Regulatory Policies Act (PURPA) in the US or Non-Fossil Fuel Obligations (NFFO) in the UK. Utility companies in Hong Kong are not obligated to procure any electricity or other LFG-derived energy from these LFG utilization plants. The combination of all these factors presents a problem for private entities interested in developing and financing an LFG utilization project. The contractors have therefore had limited success pursuing utilization schemes that will generate additional revenue.

Electricity Market

There are two electrical power utility companies in Hong Kong, each supplying power to designated, but not over-lapping, areas. Despite the global trend of electricity market de-regulation, the power market in Hong Kong is similar to a monopoly. The current market price for power (approximately USD $0.10 per kilowatt-hour) is attractive from a financial perspective for an LFG-to-electricity project. The power companies in Hong Kong, however, currently possess excess capacity for power generation and have little interest in purchasing additional power from a landfill source.

For example, it is technically feasible to install an LFG-to-electricity scheme, such that any deficiency in the power requirements of the site can be compensated by the city grid, or excess power can be exported to the grid. The electric utilities, however, will not purchase the excess. This is currently the case at one operating landfill in Hong Kong, where excess power goes back to the grid, but is not purchased. Although it may be technically and financially feasible to implement an LFG-to-electricity scheme, since there is no regulation or financial incentive for the utility to procure the power, the energy ends up wasted in a flare.

Gas Market

Most of the households in Hong Kong use Towngas as fuel for cooking and water heating. HKCG is the only gas utility in Hong Kong that produces and distributes gas (known as Towngas). Households outside the HKCG distribution network typically use bottled LPG as fuel for heating and cooking.

Towngas is produced by cracking naphtha and adding hydrogen, to arrive at a typical composition of 49%-H_2, 28.5%-CH_4 and 19.5%-CO_2, which is quite different in comparison to typical composition of natural gas in the U.S. and U.K. The cost for producing pipeline quality gas therefore involves not only stripping the LFG of contaminants to produce high Btu gas, but also preparing a gas of the correct chemical proportions for pipeline injection.

The current market price of Towngas is approximately USD $0.0011 per Mega-joule. Small and medium scale projects, are technically feasible, however, the cost is too high to justify an LFG utilization scheme of this size for producing pipeline quality gas. Larger scale projects to produce Towngas may be financially feasible (one is currently under consideration).

TEchnical considerations

A detailed design process was undertaken to evaluate potential uses for the LFG, including both on-site applications and sale of the gas (or electricity) to an end-user off-site. The intent of the design was to provide a scheme where the collected LFG could be utilized safely and reliably. The following text provides a more detailed description of the design considerations and features of the plant and equipment at the Shuen Wan and Jordan Valley Landfills.

Compression Facility at Shuen Wan Landfill

Various options were considered for the development of an LFG utilization scheme. The list of potential projects evaluated includes the following:

- Generation of electricity for on-site and off-site sales
- Direct use of LFG as a heat source
- Upgrading to pipeline quality gas
- LFG fueled leachate evaporation

Discussions regarding the potential purchase of power were initiated with the local electric utility, China Light & Power Co. Ltd. (CLP). Based on the market conditions previously discussed, CLP was not interested in the purchase of power from the landfill site.

A survey of potential energy users near the site identified several potential clients for sale of gas or electricity. One option was to supply power to the Drainage Services Department (DSD) POTW. The DSD was concerned with the reliability of the supply of power from the landfill and the potential for problems with their plant electrical controls. LFG fueled leachate evaporation was considered, but the quantity of LFG available was not sufficient to handle the volume of leachate. Another option considered was to locate an aluminum recycling facility on the landfill to utilize the energy. This option was not selected due to potential environmental impacts form the recycling operation. Upgrading the LFG to pipeline quality gas was not considered financially feasible, primarily due to the cost of producing a gas with the unique composition of Towngas. Direct use of the LFG as a fuel for a nearby industrial source appeared to be the best available option.

Numerous discussions were held with HKCG regarding potential use of LFG as fuel for process heat. In 1999, an agreement was reached between EPD, HKCG and the restoration contractor, the Hong Kong Landfill Restoration Group Ltd. (HKLRG), to beneficially utilize the LFG for 10 years (with an option for 15). The utilization scheme provides LFG as an alternative to naphtha, which is used by HKCG as fuel for process heating at their production facility.

The compression / treatment facility is located adjacent to the existing flare station. The design and construction of this facility was provided by LFG Specialties, a manufacturing subsidiary of Organic Waste Technologies (OWT). The existing LFG blowers extract and convey the LFG to the facility for compression, filtration and dehumidification. The compression facility comprises two AC belt-driven rotary vane compressors, each rated at 125HP and delivering a maximum of 2,500 Nm3/h of LFG at 3.0bar (42psi).

Each compressor is operated by an Allen-Bradley variable frequency drive (VFD) based on a pressure control scheme, with varying speed based on demand from HKCG. To ensure continuous operation and effective particulate removal, Air Coolers, Water Pumps, Lube Oil Pumps and Coalescing Filters were installed. The compressors are installed on separate skids and can be operated independent of each other. This is critical to ensure high reliability of LFG supply to a gas production plant. This arrangement also allows efficient use of electricity at different supply rates.

The compressed LFG from the two compressors then enters an LFG dryer, which chills the LFG to a dew point of 4oC, leaving virtually no water in the gas stream. This dehumidification process is essential to avoid condensate accumulation in the conveyance pipeline since it was designed with no condensate traps. The quality and quantity of LFG are recorded by an on-line gas analyzer and an on-line flow computer. HKCG is charged based on readings from these instruments on a monthly basis by HKLRG, with a royalty paid to EPD as a percentage of profit.

Since it was the first system in Hong Kong directly exporting LFG outside a landfill site, safety was prime concern to the governmental agencies responsible for approval of the scheme. The entire compression facility is monitored by programmable logic controllers (PLC), with a local operator interface to enhance daily operation and a direct link communicating with the central control console of HKCGs plant. Facility conditions are also continuously monitored by a closed-circuit television (CCTV) system. The entire plant is protected by a sophisticated fire services system in case of gas leakage or fire outbreak. The fire services system components include combustible gas detectors, sprinklers and water spray system, water hose reels, etc.

An automatic telemetry system is also in place to report any abnormal operating conditions to the operators. The compression facility itself is equipped with numerous interlocking safety features ranging from motor failure and electricity surge to abnormal gas pressure and gas quality. Redundancy in safety devices is incorporated throughout the facility by proper arrangement of devices for critical operation parameters. A typical example is the coordinated and sequential activation of over-pressure protection by an

electrical pressure switch, then a mechanical pressure relief valve, followed by an electrical modulating pressure by-pass valve.

Waste oil and condensate produced during the compression process are routed through two oil / water separators. Waste oil is properly stored and disposed of at a chemical waste disposal facility. Condensate generated during the process is directed to the leachate collection system for treatment at the POTW.

LFG-to-Electricity (LFGTE) Facility at Jordan Valley Landfill

Due to the relatively small size of the landfill and the absence of potential industrial users nearby, sale of the LFG for off-site utilization was considered not feasible and the option of on-site utilization was therefore selected. This scheme makes use of two LFG-fueled internal combustion engines to generate the electrical power supply to meet the 24-hour demand from the LPTW.

The LFG at the Jordan Valley Landfill is first extracted from the landfill using the existing LFG blowers. A tee with a pressure-controlled modulating valve was added between the blowers and the flare stack, diverting a portion of the LFG to the LFGTE facility. Excess LFG is flared automatically through a modulating valve with a pressure control loop.

The LFGTE facility comprises a fuel-conditioning skid and two internal combustion engines. The fuel-conditioning skid, manufactured by LFG Specialties, is equipped with a booster blower to meet gas pressure requirements at the engine inlet. A pressure-controlled bypass line balances momentary fluctuation of LFG demand from the engines by circulating the gas back to the booster blower inlet. The air cooler and coalescing filter at the discharge of the booster blower are employed to remove particulates and moisture (together with some soluble organic compounds), which may cause corrosion to engine components during operation. The operation of the fuel-conditioning skid is continuously monitored by a PLC, with an operator interface for ease of operation. Major alarm set points and system operation parameters can be adjusted on the operator interface.

The internal combustion engines, manufactured by Liebherr and adapted for use with LFG by Jenbacher, are capable of producing a total electrical output of 218kW, at 380VAC 3-50Hz as to local supply conditions. They are 4-stroke in-line 6-cylinder turbo-charged engines, with heat dump radiators for jacket water and inter-cooler water circuits. Combustion is based on the lean-burn principle, significantly reducing pollutant emission. The engines are self regulated and monitored by their respective microcomputers. Synchronization between the two engines is fully automatic. A combination of two engines over a single larger engine has the advantages of standby capacity and efficient operation based on electricity demand from LPTW. Another advantage of using the two engines is that one engine can be operated while maintenance is performed in the other.

Apart from monitoring the operation of the system by the respective PLC, the control scheme interlocks essential operation and safety signals to ensure reliable and safe operation. Each engine is equipped with built-in safety features ranging from over-speeding to misfiring in combustion chamber. The entire facility is protected by a comprehensive fire services system comprising combustible gas detectors, water spray system and hose reel system. The entire plant will be stopped automatically if a fire alarm is detected.

The electricity generated is connected to a low voltage switch room, where CLP supply is also connected. An electrical and mechanical interlocking changeover switch ensures no simultaneous power supply is possible, which could potentially damage system equipment and other connected loads. With the CLP supply set up as stand-by power supply, the electricity from the engines supplies all the load requirements of the LPTW until a failure in the LFGTE utilization system is detected.

Waste lube oil generated during routine operation and maintenance is properly stored and disposed of at a chemical waste treatment facility. Condensate collected in knockout pots, air cooler and coalescing filter is directed to the landfill leachate system and is pre-treated in the LPTW prior to discharge.

During the testing and commissioning of the plant, several concerns were thoroughly investigated to ensure safety and reliable operation of LFGTE system. The first involved testing the load characteristics at the LPTW in respect to their reactance and capacitance. Power factor measurements were taken at a range

of load conditions at the LPTW. The values obtained were used to determine the likeliness of engine over-speeding in case of a sudden loss of load. This is particularly important for electrical systems with power factor correction equipment installed. At selected load conditions with critical power factor values, site tests were conducted to verify safe operation. Although the engines are internally protected from over-speeding, the manufacturer does not recommend that this safety feature be activated frequently and should be avoided if possible.

Statutory Issues

From the initial design and permitting stage to actual start-up, many submittals were required to the relevant agencies and governmental authorities. A brief summary of the numerous submittals required to acquired the necessary approvals to construct and operate the facilities:

- Engineering design including
- Equipment plans and specifications
- Integration with existing plant and equipment
- Pipeline and clean-out plans and details
- Coordination with HKLRG for relevant fire services, civil and structural works
- Preparation of Hazard and Operability (HAZOP) Study Report
- Design submission to EPD and the Independent Checking Consultant retained by HKLRG with respect to the objectives of the restoration contract
- Design submission to Gas Safety Office (GSO) of Electrical and Mechanical Services Department, HKSAR, for the design of compression facility for off-site use of LFG
- Amendment of HKCGs registration as a gas-producer
- Application as a Notifiable Gas Installation (Shuen Wan Landfill only)
- Design submission to Fire Services Department (FSD) of HKSAR for approval of fire services system Design
- Submission of Work Completion Form WR1 to CLP for energization of the plant.
- Submission of Testing and Commissioning Plan and Report to GSO for approval to use
- Inspection by FSD for acceptance of the completed fire services systems
- Testing and Commissioning Plan to EPD and the Independent Checking Engineer of HKLRG

While statutory approvals are required in every location for these types of projects, the numerous design documents and submittals required for project approval in Hong Kong were particularly onerous in comparison with similar projects in the U.S. and the U.K. Additionally, the registration as a gas producer and application for the Notifiable Gas Installation would have been much more difficult and time consuming if a company other than a well established gas producing utility (HKCG) were submitting the application.

Current operation

Both LFG-to-energy systems have been operational for almost two-years, with high on-line availability. Both periodic and preventative maintenance programs are in place; however, several operation issues and problems are being dealt with on an ongoing basis.

Probably one of the most common operational challenges is how to maximize the quantity and quality of collected LFG. Both sites have exhibited differences in projected gas generation rate and actual recovery. This discrepancy is not as critical for Jordan Valley Landfill because the LFGTE facility is for on-site use only and excess gas is flared. The Shuen Wan Landfill project economics have been adversely affected because all LFG recovered is intended for export to the end user.

The variance in LFG generation and recovery rates is most likely to due to solid waste characteristics unique to the Asian region. Typical waste in Hong Kong has a much higher fraction of organic waste and

higher moisture content compared to typical U.S. landfills. As a result, a much faster decomposition takes place and the estimated peak gas production is higher than predicted. This is followed by a more rapid decline in gas generation, which has been observed at both landfills (which are in their declining phase of gas production). Higher than expected leachate levels in each landfill also impacts the gas generation and recovery rates. The above factors appear to account for the discrepancy between the expected and actual gas production rates.

Another operation issue is related to the design of the single-header system. The collection systems at both sites were designed with migration and emission control in mind, not energy recovery. This makes it an operational challenge to achieve the objectives of off-site migration control and high quality gas recovery. Considerable effort is spent to achieve a stable fuel quality for the engines.

Optimization of the system performance requires frequent well field monitoring and tuning exercises and statistical analysis of the collected data. Both sites require accurate well head tuning to ensure that gas quality remain within a specified range (CH_4 of 50～55%). This required additional effort in comparison with previous operation for flaring only, since flares have a higher tolerance to variations in CH_4 concentration.

CONCLUSIONS

LFG is utilized directly as process fuel at the Shuen Wan Landfill and converted to electricity at the Jordan Valley Landfill. Both facilities show a high on-line reliability and have significant merits to the environment. The compression and treatment facility at the Shuen Wan Landfill reduces combustion of naphtha (a derivative of fossil fuel) while controlling the LFG emissions and off-site migration. The installation and operation of this system results in a net benefit to the environment and causes a reduction in greenhouse gas emissions, thus providing an environmentally and commercially beneficial method of LFG utilization.

Since its start-up in August 1999, through the end of year 2000, about 23 million m^3 of LFG have been exported from the LFG Compression Facility at Shuen Wan. The system is anticipated to replace an equivalent of 18～24 tons of naphtha everyday and reduce 23,000 tons of CO2 in the atmosphere each year [2]. The plant has demonstrated an on-line availability of over 97%.

The LFGTE facility at Jordan Valley Landfill is an environmentally sound on-site utilization scheme with high reliability utilizing LFG for electrical power generation. Since the LFGTE facility at the Jordan Valley Landfill began operation in June of 1999, it has generated over 1 million kWh of electricity. This facility also maintains over 97-percent on-line availability.

The three active landfills in Hong Kong already generate large amounts of LFG, which will be sustainable for a long time (30 years or more). Each one of these landfills has installed LFG-to-Energy systems for on-site applications. They will likely have large quantities of LFG, or power, in excess of what they consume on site. Possible off-site LFG utilization scenarios are currently under consideration.

Rising oil prices and increases in demand for power should cause the local utilities to favor LFG-to-energy projects, because they will become more financially attractive. The environmental benefits of the LFG utilization scheme are appealing to both government and the utilities. The EPD currently encourages the utilization of LFG in Hong Kong through contract specifications. Further encouragement should come from the government in the form of incentives for the gas and power utilities to take advantage of green power. A combination of the above factors will encourage the beneficial use of LFG as a commercially attractive project, and assure that these valuable energy sources are not wasted.

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